

Control Of Algal Standing Crop By P And N In The Clark Fork River

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Abstract

In the mid and late 1980's, attached algae levels in the Clark Fork of the Columbia River varied from unnoticeable to extreme nuisance levels. This study addressed the question: are P and N levels low enough long enough to limit algal growth and standing crop in this river? If so, river reaches with nuisance levels may improve if nutrient levels are lowered, and high quality reaches may worsen if nutrient levels are allowed to increase. Because the Clark Fork often exhibits N and P levels thought to saturate algal growth, there was doubt that nutrient management would affect algal levels. Through the use of artificial stream fertilization experiments, this study showed that the standing crop of these attached algal communities saturate at much higher nutrient levels than does growth. At most river sites from Sept. 1987 to 1989, dissolved P and N were almost always below levels that saturate algal standing crop. The ratio of dissolved N:P in the water suggested that N limitation, P limitation or a balance between the two existed for significant periods of time at almost all sites. Hence management of both N and P may reduce nuisance levels (when other factors are not limiting) and are important to protecting high quality areas.

Introduction

Over the past decade citizen concern over eutrophication and nuisance algae in the Clark Fork of the Columbia River has grown. In the mid 1970's and much of the 1980's, much of western Montana experienced below average precipitation and river flow. During these low flow years, massive growths of attached algae (most noticeably the filamentous green *Cladophora*) developed in the upper Clark Fork. There is no mention of such growths before the 1970's, and it may be that toxic metals (especially Cu and Zn) released from mine wastes in the headwaters prevented the development of such massive growths. Water treatment put in place in the 1950's and 1970's greatly decreased toxic metal levels in the river.

Dissolved oxygen studies in the mid 1970's (Braico 1973) and 1980's (Watson 1989a,b) found that oxygen levels in the upper and middle Clark Fork often drop below the state standard on summer nights when water temperature is above 16-18°C. Diurnal drops in oxygen are attributable to the respiration of the benthic community. Massive growths of algae interfere with recreation while the impact of such growths on fish feeding and spawning is unknown. Attached algae levels in much of the Clark Fork exceeded nuisance criteria set by British Columbia (Watson 1989c).

While the above water quality problems showed that the Clark Fork had nuisance algae levels, the Montana Water Quality Bureau questioned whether algal levels could be managed by managing nutrients. Based on the Bureau's monitoring, the Clark Fork's total orthophosphate levels were well above P levels generally thought to saturate algal growth. However, these levels were based on unfiltered, acidified samples that occasionally contained much sediment, hence much of this P may not be available to algae. Moreover, Bothwell (1985, 1988, 1989) found that, like growth, the peak standing crop of attached diatom communities increases with soluble reactive P (SRP) levels and becomes

saturated at much higher concentrations (around 30 ppb P) than those that saturate growth (less than 1 ppb P). Although the total orthophosphate levels of the river were usually above SRP levels that saturate growth, they were frequently below levels that Bothwell found to saturate standing crop.

In 1987, the present study was undertaken to evaluate the role of nutrients in the control of nuisance algae levels in the Clark Fork River. Study objectives included: 1) determine levels of soluble inorganic P and N that saturate growth and standing crop in the Clark Fork River using artificial stream fertilization experiments; 2) compare these levels to instream soluble inorganic nutrient levels and evaluate whether these levels are low enough long enough to limit algal growth or standing crop.

The study focused on the role of P in controlling periphyton in 1988 and focused on N in 1989. Unpublished work by Bothwell (pers. comm.) suggests that growth of attached diatom communities saturates around 10 to 20 ppb N, but levels that saturate periphyton standing crop are not known. Hence, this study sought to determine these levels.

Study Design

The Clark Fork of the Columbia drains the western 22000 square miles of Montana. This study evaluated about 300 miles of river from the headwaters near Anaconda, MT, to the first large reservoir near Noxon, MT, near the Idaho border. Grab water samples were collected at 19 sites (Figure 1) from September 1987, 1.0 September 1989. In the 1987 -8 water year (an exceptionally low flow year), samples were collected monthly from September to February biweekly from March to June, and weekly from July to August. In the 1988-9 water year (an average flow Year) timing of samples was similar except that July-August sampling was monthly only. All samples were handled and analyzed for soluble reactive P (SRP) and soluble nitrates/nitrites and ammonia in accordance with Standard Methods (APHA 1985).

An artificial stream system similar to that described by Bothwell (1985) was constructed just upstream of the discharge of the Missoula Waster Water Treatment Plant. Because two tributaries that are very low in nutrients join the Clark Fork just above Missoula, this reach has some of the lowest nutrient concentrations on the river. The system pumped river water through 6 identical plexiglas troughs with lids of UV excluding Lexan (trademark), achieving flow rates of 0.4 m/s. Attached algae grew on 1/4 inch thick, open cell styrofoam (Customfoam Crafts, El Monte, CA) placed in the bottom of the troughs, allowing easy sampling for algal standing crop by coring the foam. (One exception to the use of open cell foam was the first experiment in 1988 which used closed cell styrofoam which allows less sediment and algae to accumulate). After allowing 3 to 5 days for colonization, five cores were collected twice a week from the beginning of the experiment until algal sloughing was obvious. Coring began at the downstream end of the troughs and progressed upstream overtime. Chlorophyll a was used as an indicator of standing crop and was determined by analyzing sample cores according to Standard Methods (APHA 1985). An exponential curve was fitted to the chlorophyll data from the rapid growth phase early in the experiment (following 3 to 5 days of colonization). Then the exponential rate of growth was converted to doublings per day by dividing by 0.693. At the end of the experiment, samples were collected from the streams, and a qualitative microscopic examination determined the abundance of various algal taxa in the streams.

Each stream received a different amount of nutrients, metered in constantly from high concentration solutions of KPO₄ and KNO₃. In 1988, artificial stream experiments evaluated the response of attached

algae to varying levels of SRP while inorganic N was added to raise stream concentrations by 200 ppb N. This was more than sufficient to saturate growth and was hoped to be sufficient to saturate standing crop. These nutrient additions were tested: stream 1) control, no addition; 2) 200 ppb N; 3) 200 ppb N + 5 ppb P; 4) 200 ppb N + 20 ppb P; 5) 200 ppb N + 40 ppb P; 6) 200 ppb N + 60 ppb P.

In 1989, all streams except the control received sufficient SRP to saturate standing crop (40 ppb) and inorganic N levels were varied. The additions were: stream 1) control; 2) 40 ppb P; 3) 40 ppb P + 50 ppb N; 4) 40 ppb P + 100 ppb N; 5) 40 ppb P + 250 ppb N; 6) 40 ppb P + 500 ppb N. Measured nutrient levels were generally within 10% of these targets.

In response to these nutrient additions, in early summer, the streams were allowed to be colonized by the diatoms washed in with the river water. While this experiment was in progress, artificial substrates (open cell foam anchored to concrete block) were placed in the upper river where *Cladophora* dominates the attached algae community. By late summer a stand of *Cladophora* 2 to 3 cm long had colonized this foam. After the diatom experiment was completed, the streams were cleaned out and the foam substrates colonized with *Cladophora* were placed in the streams and sampled. In both 1988 and 1989, two types of attached algal communities were evaluated for their through the late summer and early fall.

In 1988, insects were picked from the streams twice a week. In 1989, insects in incoming water were removed by a large, fine mesh net. The foam colonized with *Cladophora* was also colonized with insects. Not all of these insects could be removed without unacceptable disturbance to the algal mat.

Results

Background nutrient levels

Nutrient levels in the river water used in the artificial streams appear in Table 1. Based on Bothwell's studies, background SRP levels during all four experiments exceeded levels that saturate periphyton growth but not standing crop. In 1988 background soluble inorganic nitrogen (SIN) levels often exceeded those that Bothwell found to saturate growth, especially during the *Cladophora* experiment. Some of the very high N levels may represent sample contamination; however, it was discovered that the sewage plant had a pipe leak near the artificial stream intake. This leak was fixed before the 1989 experiments. In 1989 SIN levels were generally lower (possibly because of higher river flows) and more often were below levels that saturate growth.

Attached algae communities composition during the experiment

The diatom communities that colonized the early summer experiments in both years were similar to the communities found in the middle Clark Fork. In 1988 the community was at first dominated by a diverse assemblage of diatoms (*Achnanthes*, *Cocconeis*, *Cymbella*, *Epithemia*, *Fragilaria*, *Navicula*, *Nitzschia*, *Synedra*, *Amphora* and *Diatoma*) joined by the following green algae: *Spirogyra*, *Scenedesmus*, *Cosmarion*, *Closterium*, *Ankistrodesmus*, *Tetraspora*. By the end of the experiment these had been joined by *Pediastrum*, *Sligeoclonium* and *Sphaerocystis*. In 1989, a similar assemblage was found with the following additions: *Cladophora* and the bluegreens *Nostoc* and *Phormidium*. The substrates precolonized by *Cladophora* in the upper river were at first dominated by *Cladophora* and diatoms (predominantly *Synedra ulna* and *Diatoma vulgare*). Also common were the greens *Sligeoclonium*,

Oedogonium, *Scenedesmus*, *Cosmarium*, *Pediastrum*, *Spirogyra*, *Closterium*, and the bluegreen *Nostoc*. By the end of the experiment, these were joined by *Ankistrodesmus*, *Mougeotia*, *Ulothrix*, *Zygnema* and the bluegreen *Phormidium*. Over the course of the 1988 experiment, *Cladophora* disappeared from the artificial streams receiving no or low P additions and remained abundant in those with high P additions. In 1989, all the streams except the control had high P additions. *Cladophora* appeared to be most vigorous in the streams with the lowest N:P ratios.

Response of algal growth rates to nutrient levels

Algal growth rates (division per day) did not differ significantly between the treatments, with a few exceptions. In 1988, growth rates of the diatom community increased significantly with the addition of N alone but not when P was added as well, suggesting the N was low enough to limit growth phase of this experiment, nutrient levels in the river water flowing into the artificial streams were sometimes below 20 ppb SIN and always at or above 2 ppb SRP.

In 1989, diatom growth rates actually decreased with the addition of P alone then increased as more and more N was added, i.e., growth rates were proportional to N:P ratios. However, the growth rates achieved with the highest N additions only reached those of the control stream. Hence the background N levels during the early rapid growth phase (10 to 50 ppb N) approached or exceeded levels that saturate growth. The negative effect of low N:P ratios warrants further study.

During the 1988 *Cladophora* experiment, background nutrient levels were generally above levels that saturate diatom growth and there was no pattern to the observed growth rates that suggested that nutrient additions had all effect. During the 1989 experiment, background N levels were low enough to limit diatom growth, but the initial *Cladophora* biomass levels were near the maximum levels achieved in the 1988 experiment, and no significant increase in biomass occurred during this experiment.

Response of Peak biomass or standing crop to nutrient levels

In the variable P experiment, diatom peak biomass (figure 2a) increased very significantly with the addition of N and marginally significantly with the addition of P up to 20 ppb P. *Cladophora* peak biomass (not shown) exhibited a similar response to the addition of N and P.

In variable N experiments, diatom peak biomass (figure 2b) did not increase significantly with the addition of P alone but increased when N was also added up to 250 ppb N. *Cladophora* peak biomass (not shown) showed no response to nutrient additions again because the initial biomass levels of all the streams were near the nutrient saturated peak levels achieved in 1988. Both *Cladophora* experiments could not be started until late Sept. Hence temperature and light were likely to be more limiting than in diatom experiments, preventing the *Cladophora* community from responding to nutrient additions to the degree it might have in early or mid summer.

Discussion

The results for the diatom experiments are in good agreement with those obtained by Bothwell (1988, 1989). When N is abundant, attached algae growth appears to saturate below the background P level at this site while peak biomass or standing crop saturates between 20 and 40 ppb. Bothwell set growth saturation below 1 ppb and peak biomass saturation at 30 ppb. Through less conclusive, the *Cladophora*

experiment suggested similar SRP saturation levels for *Cladophora*. Freeman (1986) reported that physiological indicators of nutrient deficiency suggested that *Cladophora* developed P deficiency after a few days exposure to SRP levels below 4 to 5 ppb but showed no P deficiency when exposed to 9 ppb. He equated this P deficiency with growth limitation.

Because of the negative effect of the P addition on growth in the variable N addition experiment, it is difficult to establish the N level at which growth is saturated. Diatom community growth increased with each N level at which growth is saturated. Diatom community growth increased with each N addition up to 250 ppb as long as P was abundant. But the highest growth rate achieved with N additions was the same as that of the control stream. Freeman (1986) saw no evidence of N deficiency in *Cladophora* when SIN levels were above 80 ppb. We will assume Bothwell's suggested growth saturation level of 10 to 20 ppb N.

Peak biomass seemed to saturate around 250 ppb N for the diatom community, but peak biomass of the *Cladophora* community responded little to N additions in this study.

The above results suggest that changes in P or N levels may affect standing crop of a diatom dominated community when P and N levels are below 30 ppb and 250 ppb respectively (if other factors are not more critically limiting). The evidence is less conclusive for the *Cladophora* dominated community because of greater variability in *Cladophora* biomass levels, more limiting light and temperature conditions during these experiments and little biomass accumulation during the 1989 experiment. Horner et al. (1983) found that biomass accumulation of filamentous greens increased with SRP up to concentrations of 25 ppb.

What are SIN and SRP levels in the Clark Fork River over the years?

Mean SRP and SIN levels for various river sites are summarized in Figures 3 and 4. SRP levels that limit growth (<1 ppb) occur only below the confluence with the Flathead River. Levels approaching growth limitation occur just above the Missoula and Deer Lodge sewage discharge points.

SRP levels that limit standing crop (<30 ppb) are seen frequently throughout much of the river. Only the reaches below Deer Lodge, Gold Creek and the Missoula wastewater treatment plant often exhibit SRP levels that saturate standing crop (the site above Rock Creek does so less often).

As for N, the lower river sometimes exhibits soluble inorganic N (SIN) levels that limit growth (<10-20 ppb), but the annual mean SIN levels exceed this value. SIN levels are generally higher in the middle river except for the site just above the Missoula sewage plant (the location of the artificial streams), which exhibits the second lowest SIN levels on the river and among the lowest SRP levels. N rich Bitterroot River water and groundwater from the city of Missoula enter the river just below this reach. Only in parts of the upper river do SIN levels frequently approach or exceed levels that saturate standing crop (250 ppb).

Some of the river's highest *Cladophora* levels appear where N is lowest in the upper river (such as just above Rock Creek near Bonita), suggesting that the periphyton strip N from the water column and N fixation supplies some of the N needs of these growths. N fixing algae are common in this reach, including some that live symbiotically on *Cladophora*.

Which nutrient is limiting most of the time'?

While the levels of N and P in water have been used to evaluate whether either of these nutrients is likely to be limiting, the ratio of N to P is useful in evaluating which of the two most likely limits algal growth or standing crop at a specific site and time. Algal uptake rates and cellular levels of N and P are usually regarded to be more definitive indicators of nutrient deficiency than are ambient levels. However, the former are much more labor intensive and so are not available for many sites and times of year. Hence, water column N:P ratios will be used as a first assessment of limiting nutrient.

N is considered to be limiting at ratios below 5:1 to 10:1 by weight while P is expected to be limiting at ratios above 10:1 to 17:1 (Schindler 1977, Chimlidal and Vighi 1974, Tones 1987). The following will be assumed: an ambient water N:P ratio of less than 5 suggests N limitation, a ratio greater than 10 suggests P limitation and intermediate ratios a balance between these.

N:P (SRP:SRP) ratios were determined for Clark Fork water samples collected 22 times from Sept. 1987 to Sept. 1988 and 16 times from Sept. 1988 to Sept. 1989 at 22 sites from Warm Springs to the Idaho border (Figure 1). Figure 5 summarizes what portion of these samples showed N or P levels low enough to limit standing crop (i.e., $P < 30$ ppb and $N < 250$ ppb). Most sites had N or P low enough to limit crop (i.e., $P < 30$ ppb and $N < 250$ ppb). Most sites had N or P low enough to limit standing crop 100% of the time. Exceptions were the following Clark Fork sites: above the Little Blackfoot (below Deer Lodge), below Gold Creek, and below the Missoula sewage plant. Rarely, the following sites also showed levels above saturation for both nutrients: above Rock Creek, Below Milltown Dam, below the pulp mill and above and below the Thompson Reservoir. This figure also shows what portion of the samples were characterized by N limitation, P limitation or a balance. For example, in 1987-1988, the N:P ratios of the Warm Springs site suggested P limitation in 30% of the samples, N limitation in 50%, and a balance in the remainder.

When one looks at the entire river over an entire year, one sees that there is evidence for the frequent occurrence of both N and P limitation and of balance between the two. Most N:P ratios in the lower river (below the Flathead) suggest P limitation while the middle river (from below Missoula to the Flathead) is most frequently characterized by ratios that suggest N limitation or a balance. The upper river (above Missoula) is fairly complex, showing considerable differences between sites and between years. For example, above Deer Lodge, P limitation is much more common than it is below Deer Lodge, due to loading from the Deer Lodge sewage lagoons and natural sources of SRP from tributaries like Gold Creek. Some of the differences between years may be due to differences in flows and others due to the greater number of summer samples collected in 1988, which exhibited more frequent N limitation during summer in the upper river.

Lohman and Prisco (in prep) evaluated physiological indicators of nutrient deficiency in Clark Fork *Cladophora* collected below Deer Lodge (June to Oct. 1990) and below Gold Creek (fall 1989). They found evidence of N deficiency at these sites and times, which is in general agreement with predictions made by ambient levels.

Conclusions

Based on artificial stream fertilization experiments, dissolved P levels below 30 ppb and N levels below 250 ppb can limit attached algae standing crop. Based on two years of dissolved nutrient sampling in the

Clark Fork River, dissolved N and P levels appear to be low enough to limit standing crop in much of the river much of the year. When the entire river is considered, N:P ratios suggest both N and P play important roles in limiting algal levels. Hence controlling these nutrients has the potential to affect algal standing crops in much of the river unless other factors are limiting.

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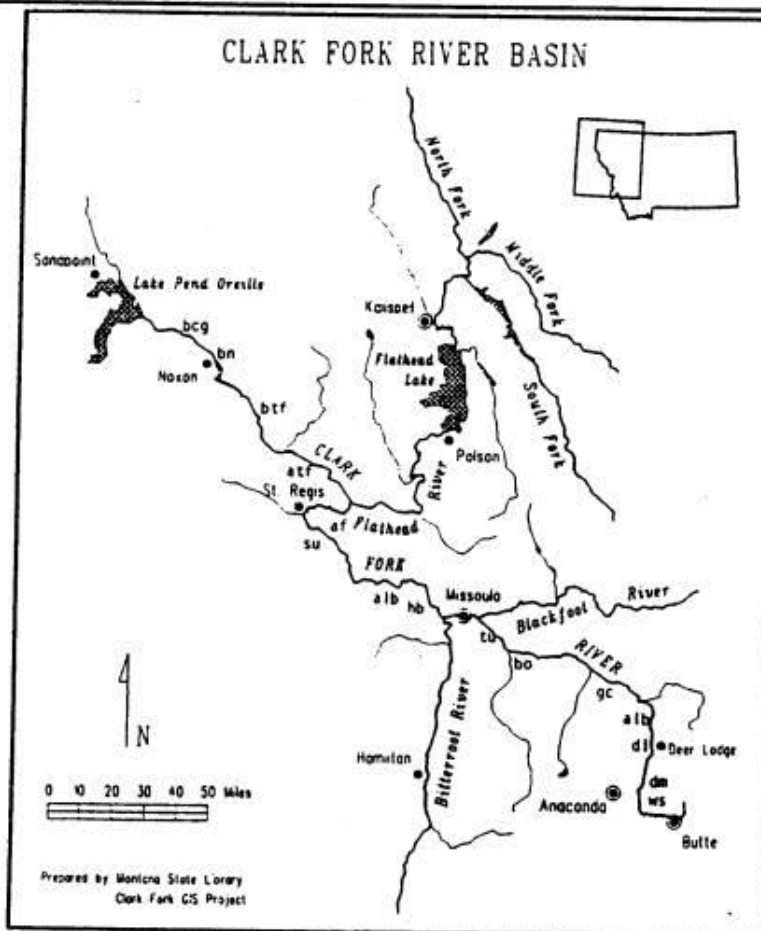
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Figure 1: The Clark Fork of the Columbia, Montana, showing the ambient water sampling stations and the site of the artificial streams, Missoula.



STATION LEGEND

DESCRIPTION OF STATIONS ON THE CLARK FORK RIVER AND TRIBUTARIES

STATION ID	RIVER MILE	DESCRIPTION
WS	0	AT WARM SPRINGS (NEAR ANACONDA)
DM	22	NEAR DEMPSEY
DL	33	AS RIVER ENTERS DEER LODGE
ALB	48	ABOVE LITTLE BLACKFOOT RIVER
GC	61	BELOW GOLD CREEK. ABOVE FLINT CREEK
BO	112	ABOVE ROCK CREEK (BEAVERTAIL HILL CAMPGROUND)
TU	130	BELOW ROCK CREEK (TORAH FISHING ACCESS)
BF	136	BLACKFOOT RIVER ABOVE BONNER
BMT	138	BELOW BLACKFOOT RIVER AND MILLTOWN DAM
AM	145	ABOVE MISSOULA WASTEWATER PLANT
BM	147	BELOW WASTEWATER PLANT'S MIXING ZONE
BR	150	BITTERROOT RIVER AT MACLAY BRIDGE
HB	158	BELOW BITTERROOT RIVER (HARPER BRIDGE)
HU	170	BELOW PULP MILL MIXING ZONE (NEAR HUSON)
AL	180	ABOVE ALBERTON
SU	218	AT SUPERIOR
AF	257	ABOVE FLATHEAD RIVER
FH	258	FLATHEAD RIVER (NEAR CONFLUENCE)
ATF	282	ABOVE THOMPSON RIVER (AND RESERVOIR)
BTf	302	BELOW THOMPSON RIVER (AND RESERVOIR)
BN	339	BELOW NOXON RESERVOIR
BCG	361	BELOW CABINET GORGE RESERVOIR (5 MILES ABOVE LAKE PEND OREILLE)

Table 1. Background Nutrient Concentrations During Artificial Stream Studies and Calculated N:P Ratios In The Different Treatment Streams.

DIATOM EXPERIMENT, VARIED P ADDITIONS					CALCULATED N:P RATIOS IN STREAMS					
DATE	SRP ppb	NH4 ppb	NO3 ppb	SIN ppb	SIN/SRP					
					STRM 1	2	3	4	5	6
880816 to 880905					CONTROL	+200 ppb N				
mean						P added: 5	20	40	60ppb	
std error	3	7	16	23	8	92	29	10	5	4
n	0.4	1.1	5.8	5.8	1.5	9.7	1.1	0.2	0.1	0.1
880816 *	4	<10	20	20-30						
880913 *	2	<10	<10	0-20						
CLADOPHORA EXP., VARIED P ADDITIONS					CALCULATED N:P RATIOS IN STREAMS					
DATE	SRP ppb	NH4 ppb	NO3 ppb	SIN ppb	SIN/SRP					
					STRM 1	2	3	4	5	6
880916 to 881005					CONTROL	+200 ppb N				
mean	2	54	8	62	43	172	37	20	40	60ppb
std error	0.6	7.6	0.0	7.6	15.1	49.7	4.0	12	6	4
n	4							0.6	0.2	0.2
DIATOM EXPERIMENT, VARIED N ADDITIONS					CALCULATED N:P RATIOS IN STREAMS					
DATE	SRP ppb	NH4 ppb	NO3 ppb	SIN ppb	SIN/SRP					
					STRM 1	2	3	4	5	6
890728 to 890901					CONTROL	+40 ppb P				
mean	5	9	9	19	4	0	2	3	6	12
std error	1.3	1.6	3.6	5	1.1	0.1	0.1	0.1	0.1	0.3
n	8									
890718 *	5	<10	10	10-20						
890814 *	8	<10	<10	0-20						
CLADOPHORA EXP., VARIED N ADDITIONS					CALCULATED N:P RATIOS IN STREAMS					
DATE	SRP ppb	NH4 ppb	NO3 ppb	SIN ppb	SIN/SRP					
					STRM 1	2	3	4	5	6
890927 to 891013					CONTROL	+40 ppb P				
mean	3.5	3.5	2.6	6.1	2	0.1	1	2	6	12
std error	0.5	0.3	1.1	1.3	0.2	0.0	0.0	0.0	0.0	0.1
n	4									
890919 *	4	<10	<10	0-20						
891017 *	4	<10	20	20-30						

* Based on Montana Water Quality Bureau monitoring just upstream of the artificial streams. All other samples were collected in control stream.
 SRP = soluble reactive phosphorus; SIN = soluble inorganic nitrogen = NH4+NO3
 NH4 = ammonia nitrogen; NO3 = nitrate and nitrite nitrogen.

Figure 2: Response of peak biomass of a diatom dominated community to additions of nutrients. a. varying additions of SRP (200 ppb SIN added to all streams but the first); b. varying additions of SIN (40 ppb SRP added to all streams but the first).

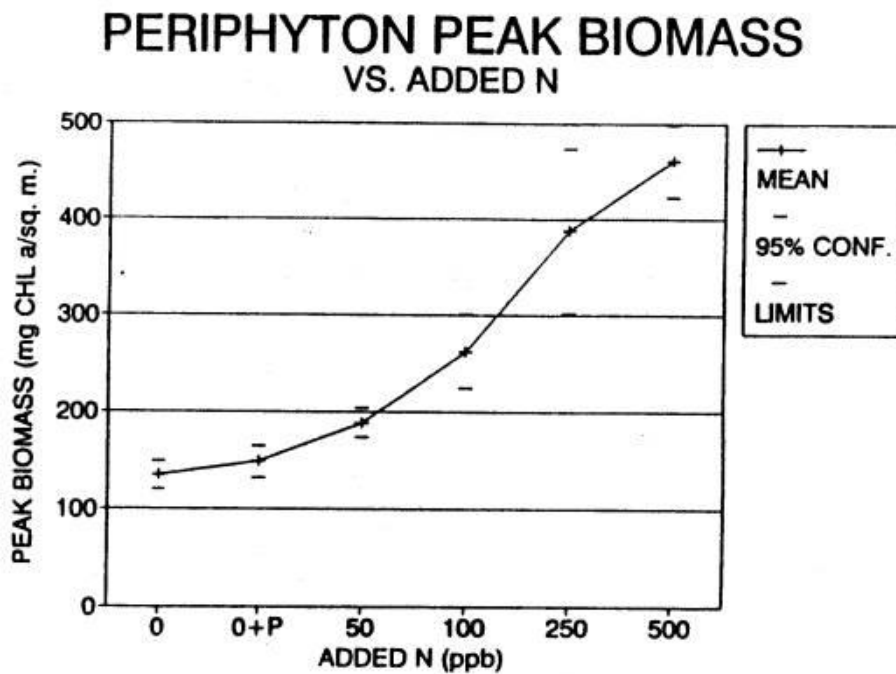
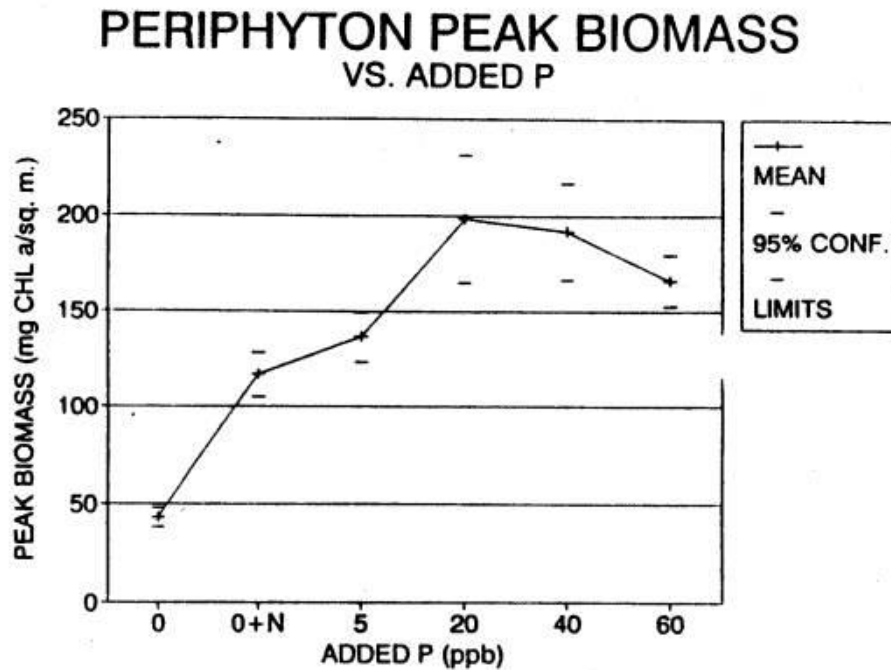


Figure 3: SRP (soluble reactive phosphorus) levels at 19 stations on the Clark Fork. a. averages 22 samplings from Sept. 1987 to Sept. 1988; b. averages 16 samplings from Sept. 1988 to Sept. 1989. Means (+) are bracketed by 95% confidence intervals. River miles are miles below confluence of Warm Springs, Mill-Willow and Silver Bow Creeks.

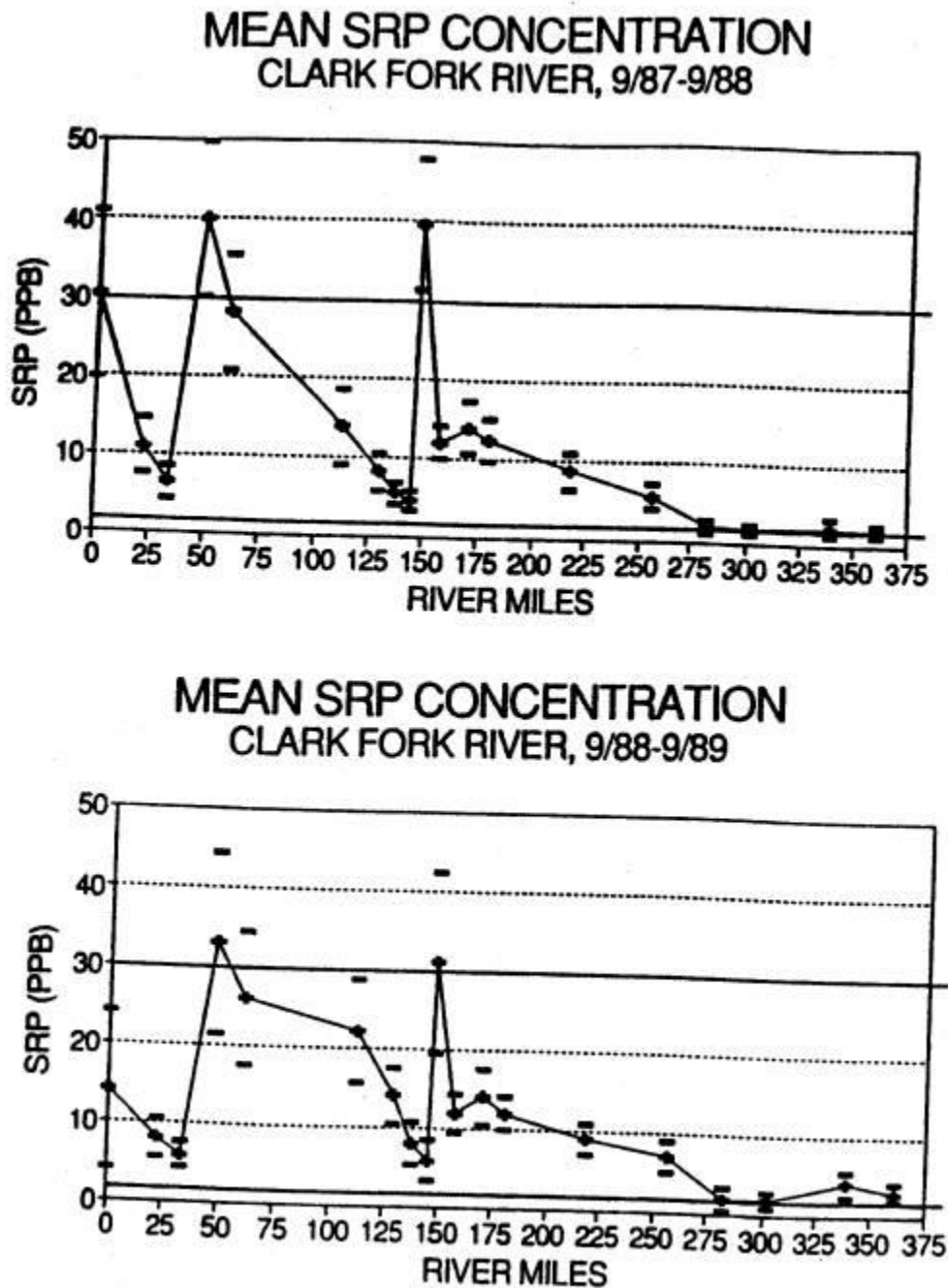


Figure 4: SIN (soluble inorganic nitrogen) levels represented as in Figure 3.

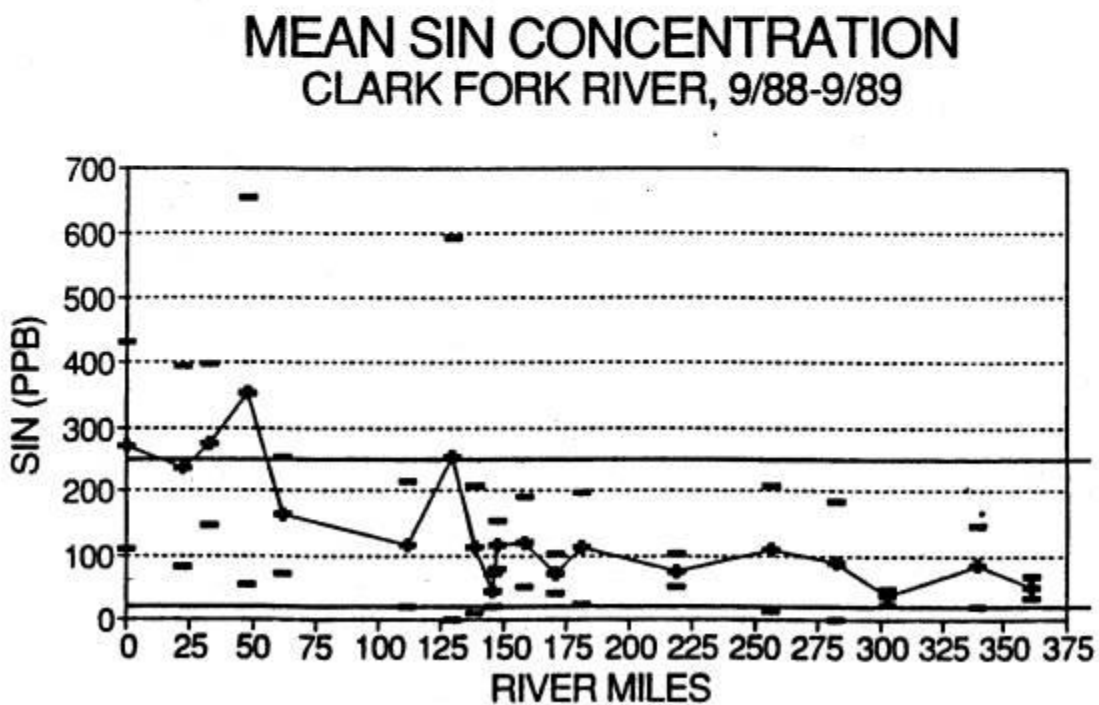
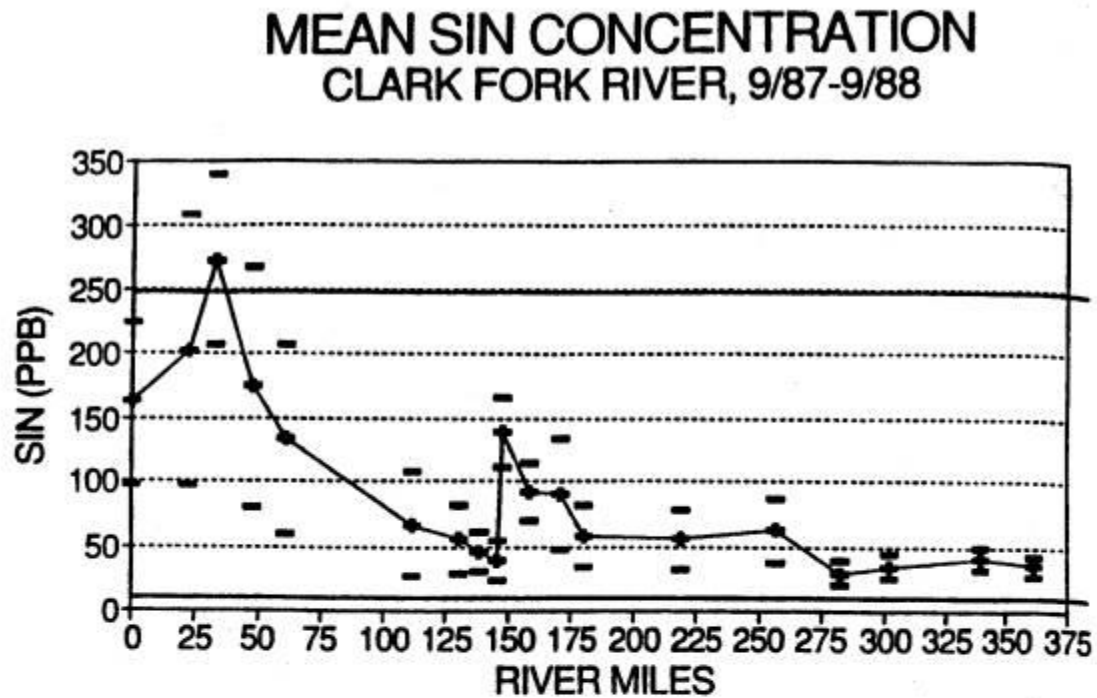


Figure 5: For 19 sites on the Clark Fork, the frequency of SIN and SRP levels low enough to limit algal standing crop and the frequency of SIN:SRP levels that suggest N or P limitation or a balance between the two. a. includes 22 samples from Sept. 1987 to Sept. 1988; b. includes 16 samples from Sept. 1988.

